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Tunisian Soil Organic Carbon Stock - Spatial and Vertical Variation

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Abstract

Soil organic carbon (SOC) is of big importance in the global carbon cycle. Distribution patterns of SOC in various regions of Tunisia constitute a baseline for studies on soil carbon changes. This paper presents Tunisian SOC stock calculated using soil profile descriptions defined by FAO/UNESCO classification, and the digital soil map 1:500 000. A soil database has been compiled, containing data from 5024 horizons and 1483 profiles. SOC stocks have been calculated for each profile by a classical method for a given depth, it consists of summing SOC stocks by layer determined as a product of bulk density (D_b), organic carbon (OC) content, and layer thickness. D_b values were calculated from pedotransfer functions when we have missing values. SOC stocks by profiles were calculated and linked by soil type to polygons of a digital soil map of Tunisia. In total, Tunisian SOC stocks are 1.006 Pg C in the 0 to 100 cm soil depth, and 0.405 Pg C in the upper layer 0-30 cm. The surface horizon (0 – 30 cm) stored 40 % of the soil organic carbon stock. OC stocks were higher in Luvisols 71.6 and 159.2 t/ha in 0 – 30 and 0-100 cm soil depth, respectively. In Podzoluvisols there are 6.19 and 138.8 t/ha, but amounts are lower in Lithosols at 18.4 and 40.4 t/ha.

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Keywords: Database; carbon pools; sequestration; aridisoils; Tunisia

1. Introduction

The global scientific community is now aware of the climate change that our planet Earth is in the process of knowing. For this, several meetings were organized during the last decades and many conventions were signed. There are clear linkages between the United Nation Convention to Combat Desertification (UNCCD) mandate and the United Nation Framework Convention on Climate Change (UNFCCC). One of the most evident linkages

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concerns the soil organic carbon (SOC) status of the soils. SOC is a good indicator and a major determinant of soil fertility, water holding capacity and biological activity and is highly correlated to levels of above and below-ground biodiversity. SOC also influences soil structure, friability and aggregation, which have major implications for soil permeability and erodibility [1]. Global climate change threats and the contribution of SOC stock to its mitigation have demanded national estimates of soil carbon stocks [2]. SOC stock is the biggest ecosystem carbon reservoir in the world; 1500 – 2000 Pg C at 0 – 100 cm [3, 4]. A good estimation from carbon pools in the soils has been suggested as a means to help mitigate atmospheric CO_2 increases and anticipated changes in climate [5, 6]. Regional and global estimates of soil carbon stocks had to be made by extrapolating means of soil carbon content for broad categories of types of soils or vegetation across the areas occupied by those categories [3, 7]. Regarding the soil compartment, global carbon pools are difficult to estimate because of still limited knowledge about specific properties of soil types [8, 3], and the high spatial variability of soil OC even within one soil map unit. Thus, regional studies are necessary to refine global estimates, mainly at country scale. SOC density according to soil type was estimated by calculating the mean SOC density of its sub-type soils weighted by their area; then SOC storage of the soil type was calculated by multiplying its SOC density by its area obtained from a digital soil map [9]. For Tunisia, it is important to assess the pools of SOC for several reasons. OC is one of the most important constituents of soils; it has a main interest agronomic and environmental. Also, OC storage in Tunisian soils reflects the capacity of arid and semi-arid regions to sequester OC. The objective of this study is to assess and give consistent values and distribution maps, for the 0 to 30 cm and 0 to 1 m depth of the organic carbon stocks in the soils of Tunisia.

2. Materials and methods

2.1. Study area

Tunisia (32°38°N; 7°12°E) situated in north of Africa and in south of Mediterranean Sea (Fig. 1), has a wide range of natural regions. It is located at the junction of the western and oriental Mediterranean and covering a surface of 164000 km^2, of which more than 67% are under semiarid and arid climate and the rest are under sub-humid and humid climate. In spite of this small surface, nor the climate neither the vegetation are uniform. In fact, the geographical position and the general orientation of the topography are influenced at the North by the Mediterranean Sea and at the South by the Sahara.

Fig. 1. Location of Tunisia in the Mediterranean Basin.

2.2. Soil database

A database was built from analytical results from Tunisian soil profile information. Chosen profiles have variable depth, but they are usually more than one meter in depth. The data contained information on organic carbon in soil (fraction < 2 mm; Walkley-Black method), pH (measured in water 1:1), bulk density (D_b) (Cylindre method; Mg m-3), granulometric fraction (after dispersion with sodium hexametaphosphate of soils), Clay (particle 0-2 µm), Silt (fine and coarse 2-50 µm), Sand (fine and coarse; 50-2000 µm) and $CaCO_3$ (Carbonate of calcium measured with Bernard calcimeter method). The entire soil database comprised 1483 soil profiles corresponding to 5024 soil horizons.

2.3. Descriptive statistics of the entire database:

The number of observations varied between 707 and 4716 due to some missing data. The mean D_b value was 1.60 varying between 0.68 and 2 Mg/m^3 (Table 1). All chemical properties, except pH measurements, had a coefficient of variation (CV) > 87 %. The OC contents ranged from 0 to 8.99 %, and had a CV of 104 %. This huge variation in the OC content is due to the great differentiation between the bioclimatic zones in Tunisia.

Table 1. Descriptive statistics for the entire database.

	Valid cases	Minimum	Maximum	Mean	SD*	CV¤ (%)
Clay (%)	4595	0.00	88.85	23.76	16.79	71
Fine silt (%)	4433	0.00	62.00	13.96	10.73	77
Coarse silt (%)	4429	0.00	56.00	10.24	6.43	63
Fine sand (%)	4388	0.00	89.00	29.73	18.86	63
Coarse sand (%)	4618	0.00	96.00	21.03	19.78	94
pH	3642	4.45	9.95	7.81	0.95	12
OC (%)	4716	0.00	8.99	0.71	0.74	104
D_b Mg/m^3	707	0.68	2.00	1.60	0.21	13
$CaCO_3$ (%)	3600	0.00	160.00	17.18	15.01	87

*Standard deviation, ¤ Coefficient of variation.

2.4. Soil map

The soil map was constructed by the Tunisian Ministry of Agriculture in 1973 at the scale (1:500 000). Nine big orders of soils have inventoried; Lithosols, Regosols, Cambisols, Vertisols, Kastanozems, Podzoluvisools, Luvisols, Solonchaks and Gleysols. We digitized this map in the period 2006-2007. The total number of soil map units was 34049.

2.5. D_b and stoniness estimation

In Tunisia, bulk density (D_b) is not determined in most routine analyses, and for most of soil profiles in the database no D_b was reported. The D_b of only 707 soil horizons from the 5024 records have been measured, and it is therefore necessary to estimate D_b's for the rest of the horizons. To this end, so values have to be determined using pedotransfer functions (PTF) [3, 7]. Using all the available parameters, results showed that:

- for superficial layers (≤ 30 cm) were:

D_b = 0.9 (±0.1) – 0.08 (±0.01) OC + 0.007 (±0.001) F-Sand + 0.007(±0.002) F-Silt + 0.05 (±0.01) pH. (R^2=0.58, SE=0.14).

- and for deep horizons layers (> 30 cm):

D_b = 1.90 (±0.02) – 0.08 (±0.03) OC – 0.0031 (±0.0009) Clay – 0.0023 (±0.0007) $CaCO_3$. (R^2=0.3, SE=0.14).

2.6. Procedure for determining the individual SOC stocks

To estimate SOC stocks, requires knowledge of the vertical distribution of OC in profiles. The way of calculating SOC stocks for a given depth consists of summing SOC Stocks by layer determined as a product of D_b, OC concentration, and layer thickness. For an individual profile with n layers, we estimated the organic carbon stock by the following equation number (1):

$$\mathrm{SOCs} = \sum_{i=1}^{n} Db_i \times \mathrm{OC}_i \times \mathrm{D}_i \qquad (1)$$

where SOCs is the soil organic carbon stock (kg $C.m^{-2}$), $D_b i$ is the bulk density ($Mg.m^{-3}$) of layer i, OCi is the proportion of organic carbon (g $C.g^{-1}$) in layer i, Di is the thickness of this layer (cm). Next step of calculation, SOC density of each great order was multiplied by its respective area to estimate SOC storage for each soil map units. Summation of individually of carbon of the nine great soil orders gave total carbon stock in Tunisia.

3. Results and discussion

3.1. Distribution of SOC density and SOC storage in Tunisia

Statistical results, exposed in Table 2, based on big soil orders, indicated that SOC density varied considerably. Table 2 showed that in 0-30 and 0-100cm depth, Luvisols have the highest SOC densities 71.6 and 159.2 t/ha, respectively. But Lithosols have the lowest SOC densities, at 0-30 and 0-100 cm it have 18.4 and 40.4 t/ha, correspondingly. Given a total area of 15520249.8 ha of soil in Tunisia, summation of all soil map units yielded a total SOC storage of 1.006 Pg C in the 0 to 100cm soil depth, and 0.405 Pg C in the upper layer 0-30 cm, and a mean SOC density of 64.86 and 26.12 t/ha at 0-100 and 0-30 cm, respectively. Changes in the relative distribution of soil organic carbon stocks with depth have been showed in table 2, the ratio of the total SOC storage of 0-30 cm (405.43 Mt) divided by that in the 0-100cm zone (1006.71 Mt).

More than 40 % of the total SOCS in the upper 100 cm of mineral soil is held in the first 30 cm.

3.2. Elaboration of maps of SOC density

In order to appreciate the geographical distribution of SOC densities and its pattern it is useful to create a map of SOC concentrations. Using as for this the digitized map of soil and the SOC density of the 1483 soil profiles, a SOC density map was constructed. Figure 2 shows that soils have different influences on the OC distribution, depending of the geographical localization, heterogeneity of climate, and geology, which determine the storage of organic carbon in soils.

Table 2. Soil organic carbon (SOC) density and storage by soil order in Tunisia.

Soil order	0-30cm				0-100cm			
	N*	SOC density t/ha	SD¤	SOC storage Mt	N*	SOC density t/ha	SD¤	SOC storage Mt
Lithosols	88	18.40	1.48	73.22	63	40.40	2.52	160.76
Regosols	261	31.50	1.97	119.83	145	83.90	4.80	319.16
Cambisols	374	41.60	2.47	100.35	212	101.80	5.77	245.57
Vertisols	80	45.60	2.00	6.75	45	109.70	5.00	16.24
Kastanozems	204	37.40	1.94	51.42	124	93.30	4.37	128.26
Podzoluvisols	170	61.90	2.82	8.78	121	138.80	6.08	19.86
Luvisols	90	71.60	3.73	4.24	60	159.20	7.62	9.43
Solonchaks	100	28.20	1.68	38.39	61	75.00	4.85	102.11
Gleysols	116	34.80	2.20	2.46	62	77.70	4.21	5.50
Total	1483			405.43	893			1006.71

* Number of soil profiles existing in database; ¤ Standard deviation.

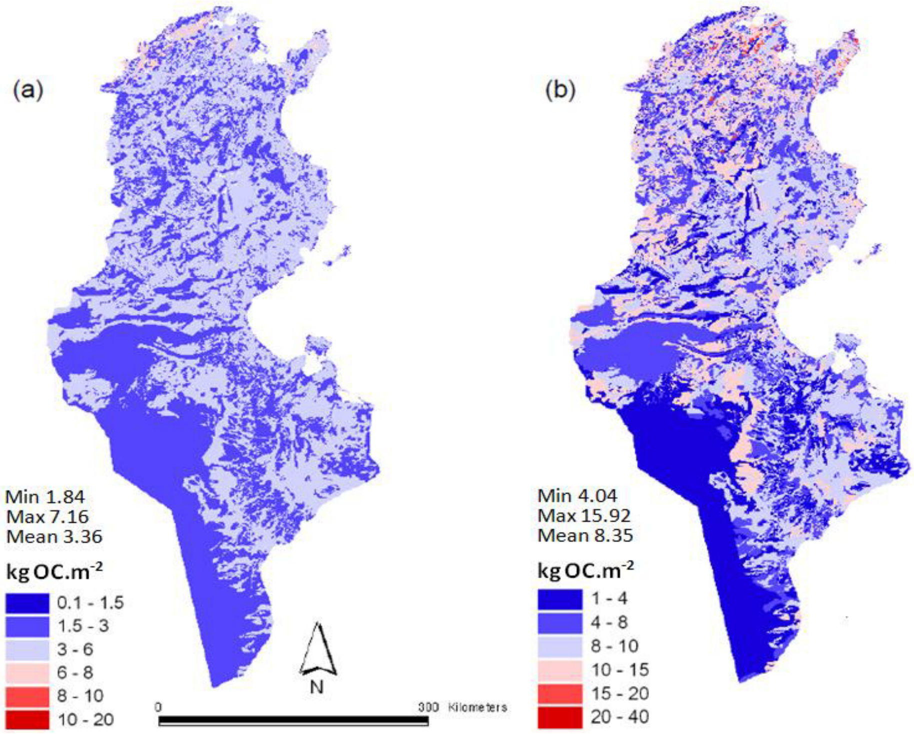

Fig. 2. Maps of SOC density of Tunisia (a) in 0-30cm depth; (b) in 0-100cm depth.

3.3. SOC density of great geographic regions in Tunisia

Statistics based on 35007 soil polygons for the SOC density ($kg.m^{-2}$) vector map of Tunisia (Fig. 2) show that SOC density and stock in various polygons varied considerably, with the lowest SOC density at 0-30 cm depth 1.84 kg $OC.m^{-2}$, and the highest 7.16 kg $OC.m^{-2}$. Among the great geographic regions, North Tunisia (North-East and North-West) stores the highest amount of soil carbon, example at 0-30 cm depth with an SOC density of 5.14 to 5.89 kg $OC.m^{-2}$, and the lowest SOC density is found in South Tunisia, 1.87 to 1.98 kg $OC.m^{-2}$ (Table 3).

Table 3. SOC density of great geographic regions in Tunisia

Great region in Tunisia	Included provinces	Total area km^2	SOC density 0-30cm depth kg $OC.m^{-2}$	SOC density 0-100cm depth kg $OC.m^{-2}$
North-East	Bizerte, Ariana, Tunis, Ben Arous, Manouba, Nabeul, Zaghouan	11985,01	5.14	12.03
North-West	Jendouba, Beja, Kef, Siliana	16479,72	5.89	13.37
Central-East	Sousse, Monastir, Kairouan, Mahdia, Sfax	20144,21	3.47	9.01
Central-West	Kasserine, Sidi Bouzid, Gafsa	23186,85	4.01	8.53
South-East	Gabes, Mednine	16783,77	1.87	4.60
South-West	Kebili, Tozeur, Tataouine	75419,84	1.98	5.41

3.4. Comparison between Tunisian SOC densities of nine big orders with similar soil orders in the world

These stocks are consistent with data for the world level [3] derived from the WISE (World Inventory of Soil Emission Potentials) soil database. Batjes (1996) [3] reported worldwide mean carbon stock values for the 0 to 30cm layer of 31, 45 and 50 $t.ha^{-1}$ for Regosols, Vertisols and Cambisols, respectively. It accounted for 0 to 100cm depth of 96, 111 and 96 $t.ha^{-1}$ for Kastanozems, Vertisols and Cambisols, respectively. But Batjes (1996) [3] calculated for the soils of arid zone slightly higher values for Lithosols (36 $t.ha^{-1}$) and for Gleysols (77 and 131 $t.ha^{-1}$, respectively for 0-30 and 0-100cm) and lower values for Solonchaks, Luvisols and Podzoluvisols (18, 31 and 56 $t.ha^{-1}$, respectively). When the international database of Batjes (1996) [3] derived from the WISE data is used for Gleysols, the estimated total carbon for this group is high, presumably because the international database includes several Gleysols from other regions that contain more carbon than the Tunisian soils.

Generally, South country regions are characterized by low SOC stocks and sandy soils which showed an important climatic influence. This sector surround semi-arid and arid zones and SOC values have ranged between 0.1 and 3 kg C m^{-2} in superficial layer (0-30 cm) the same as between 1 and 8 kg C m^{-2} at 1 m depth. Clay with high surface area protects organic carbon from decomposition on developing stable clay-organic carbon complexes [10, 11]. Organic carbon associated with sand particles was readily decomposable as compared to that in silt and clay [11]. Singh et al., (2007) [10] confirmed that intensive agriculture without proper management in the semi-arid region was the cause of rapid SOC reduction in cropland as compared untilled soils under scrub vegetation.

In similar conditions in Jordan if climate change and/or human land uses alter these lands, then soil carbon storage could decline [12]. Changes in soil carbon storage, either positive or negative, are unlikely to be uniform throughout the globe, because the distribution of soil carbon stocks, the factors that stabilize soil carbon and the forces that contribute to change vary widely among regions. Moreover, mean annual rainfall, tillage, period of canopy cover, clay content, land use history and productivity have pronounced effects on SOC stocks [13, 14]. Bernoux et al., (2002) [7] showed several sources of uncertainties with national SOC stocks estimation, because the information from soil database stem different sources and the methodology used for the analyses of organic carbon content and Db may be varied among different laboratories.

Present results are in support of previous work and provide more details for aridisols. Indeed, related to previous findings from Tunisian soil carbon stocks, the calculated SOC stocks to 0-30 cm using the FAO world soils database were closed to the amount 0.498 Pg C reported by [15] Henry et al., (2009), however the estimated stocks to one meter were lesser than the result (0.727 Pg C).

4. Conclusion

Soils in Tunisia stored 1.006 Pg C and a mean SOC density of 6.486 $kgC.m^{-2}$ within the 100 cm soil depth and 405.44 TgC in the upper layer 0-30 cm within a mean SOC density 2.612 $kgC.m^{-2}$. Soil organic carbon is very spatially variable at the scale of the maps. This could have been easily anticipated, given the large spatial heterogeneity of climate, geology and land use in Tunisia, which determines inter alia the storage of organic matter in soils. Zones with a high OC content correspond generally with areas of high rainfall; natural forests and mountain ranges in the North of Tunisia, whereas the South with low rainfall show little SOC density. Due to application of the calculated profile values method for estimating SOC density and linkage with soil map, the results of this first study for estimation Tunisian SOC stock were accurate and reliable.

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References

[1] N. Brahim, M. Bernoux, T. Gallali, Pedotransfer functions to estimate soil bulk density for Northern Africa: Tunisia case. J. Arid Environ., 81 (2012) 77-83.
[2] H. Eswaran, E. Van Den Berg, P. Reich, Organic carbon in soils of the world. Soil Science Society of America Journal, 57 (1993) 192-194.
[3] N.H. Batjes, Total carbon and nitrogen in the soils of the world. European Journal of Soil Science, 47 (1996) 151-163.
[4] IPCC, Good practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Institute for Global Environmental Strategies (IGES) for the IPCC. (Hayama JP), 2001.
[5] N.H. Batjes, W.G. Sombroek, Possibilities for carbon sequestration in tropical and subtropical soils. Global Change Biology, 3 (1997) 161-173.
[6] R. Lal, J.M. Kimble, R.F. Follett, C.V. Cole, The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Ann Arbor Press, Chelsea MI. 1998.
[7] M. Bernoux, M.D.S. Carvalho, B. Volkoff, C.C. Cerri, Brazil's soil carbon stocks. Soil Science Society of America Journal 66 (2002) 888-896.
[8] W.G. Sombroek, F.O. Nachtergaele, A. Hebel, Amounts, dynamics and sequestration carbon in tropical and subtropical soils. Ambio 22 (1993) 417-426.
[9] D.S. Yu, X.Z. Shi, H.J. Wang, W.X. Sun, E.D. Warner, Q.H. Liu. National scale analysis of soil organic carbon storage in China based on Chinese Soil Taxonomy. Pedosphere, 17 (2007) 11-18.
[10] S.K. Singh, A.K. Singh, B.K. Sharma, J.C. Tarafdar, Carbon stock and organic carbon dynamics in soils of Rajasthan, India. J. Arid Environ., 68 (2007) 408-421.
[11] N. Brahim, D. Blavet, T. Gallali, M. Bernoux, Application of structural equation modeling for assessing relationships between organic carbon and soil properties in semiarid Mediterranean region. Int. J. Environ. Sci. Tech., 8 (2011), 305-320.
[12] N.H. Batjes, Soil carbon stocks of Jordan and projected changes upon improved management of croplands. Geoderma, 132 (2006) 361-371.
[13] H. Ibrahim, A. Hatira, M. Pansu, Modelling the functional role of microorganisms in the daily exchanges of carbon between atmosphere, plants and soil. Procedia Environmental Sciences, (2013) 96-105.
[14] N. Brahim, T. Gallali, M. Bernoux, Effects of agronomic practices on the soil carbon storage potential in Northern Tunisia. Asian J. Agric. Res., 3 (2009) 55-66.
[15] M. Henry, R. Valentini, M. Bernoux,. Soil carbon stocks in ecoregions of Africa. Biogeosci. Discuss, 6 (2009) 797-823.